THE AGE OF THE DOMES AND ANTICLINES IN THE LOST SOLDIER–FERRIS DISTRICT, WYOMING[1]

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INTRODUCTION

The relative age of the major and minor folding in Wyoming is a somewhat mooted question among geologists, especially among those who are interested in the problems of oil and gas accumulation. In a recent paper Ball[2] reached the conclusion that nearly all the minor folds of Wyoming were formed during the period of formation of the major uplifts. That exceptions to this general rule may exist is frankly admitted by Ball, and he cites the Simpsons Ridge fold as the one example with which he is familiar of an uplift in which the minor folding is clearly younger than most of the major folding. Although agreeing in general with Ball's conclusion, the writer believes that exceptions to the rule are more numerous than Ball suggests. He believes further that a most noteworthy exception to the rule is to be found in the folds of the Lost Soldier–Ferris oil and gas district of south-central Wyoming, the age relations of which are here discussed.

GEOGRAPHIC AND GEOLOGIC RELATIONS

The Rawlins uplift, in south-central Wyoming, is about fifty miles in length and twenty miles in width and trends in a northerly direction (see map). It is not large enough to be classed among

[1] Published with the permission of the Director of the United States Geological Survey. The information presented in this paper was obtained in the summer of 1920, during an examination made to obtain data for classifying the public land in the oil and gas fields of the Lost Soldier–Ferris district. The results of this examination are being prepared for publication by the United States Geological Survey.

[2] Max W. Ball, "The Relative Ages of Major and Minor Folding and Oil Accumulation in Wyoming," *Amer. Assoc. Petroleum Geologists, Bull.* 5 (1921), No. 1, pp. 49–63.

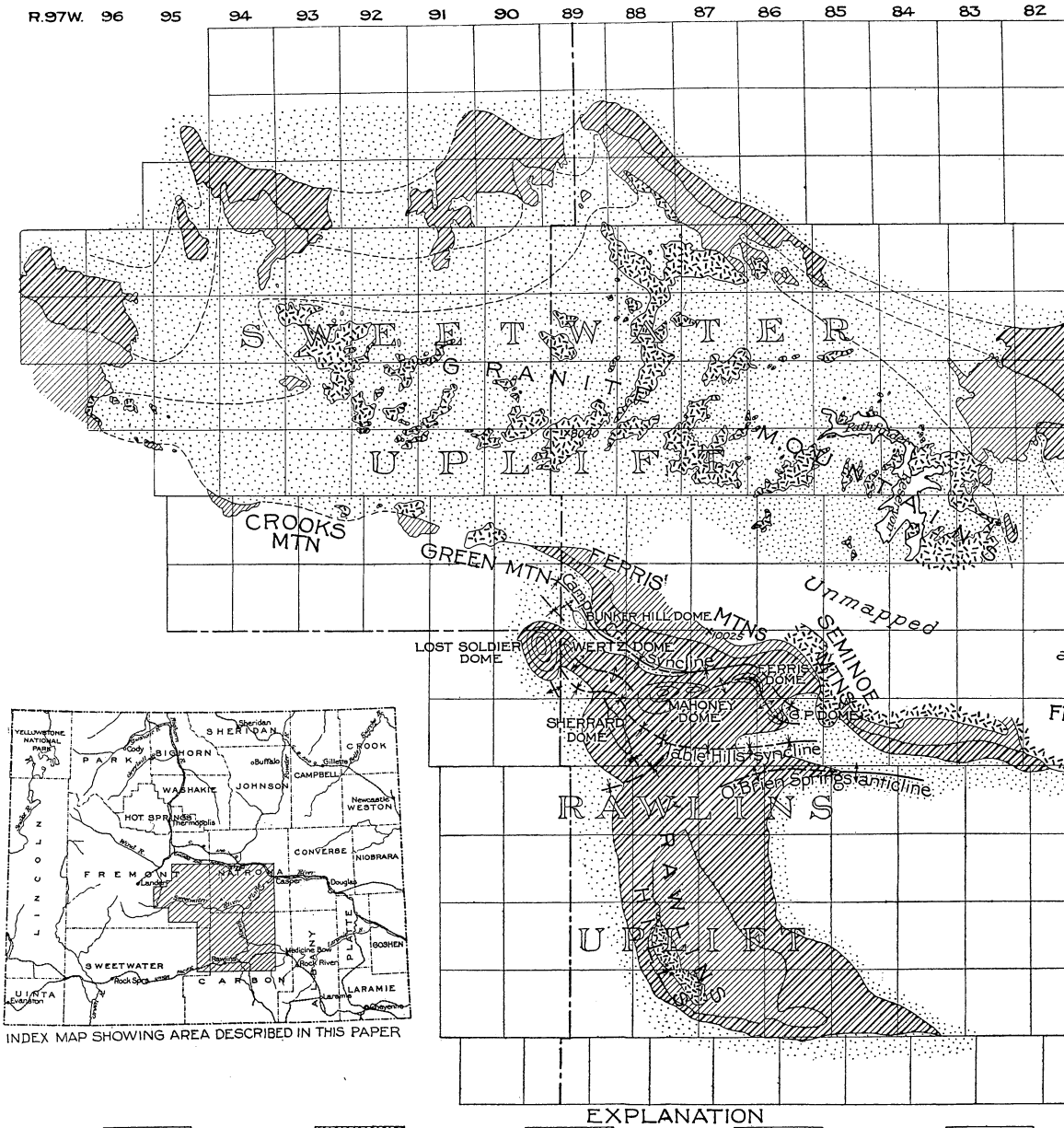
the major uplifts in Wyoming on account of its size, but the fact that its central axis is elevated so high that the pre-Cambrian rocks are now exposed at the surface is sufficient, as pointed out by Ball,[1] to justify ranking it as a major uplift. Its alignment makes it a part of that series of Rocky Mountain flexures characterized by northerly lines of folding and faulting. It is to be noted especially that the Rawlins uplift is one of a group that forms the northernmost member of this northerly series, beyond which the Rocky Mountain folds abruptly change in direction to a transverse series with east-west trend, of which the Sweetwater uplift, described below, is one.

From the general horizontal position of the Wasatch beds on the west flank of the Rawlins uplift, it seems certain that the development of this uplift was complete, or practically complete, by the beginning of Wasatch time.

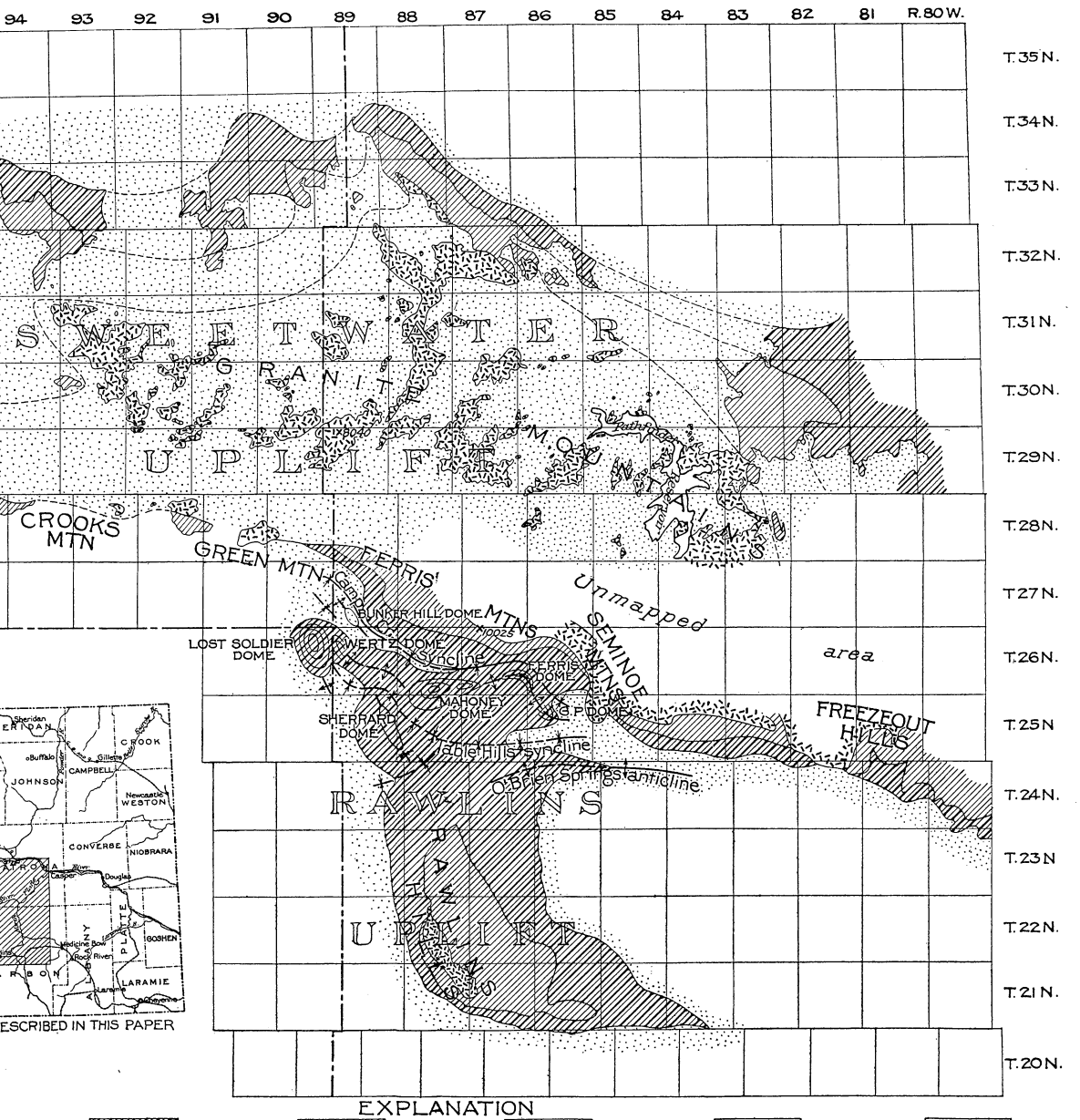
The central pre-Cambrian granite core of the Rawlins uplift is faulted along its west side, and toward the north this fault zone turns northeastward and crosses the axis of the fold. The portion of the uplift north of this fault is on the down-dropped side, and this lower-lying north end of the uplift is occupied by the oil and gas fields of the Lost Soldier–Ferris district. The oil and gas accumulations of this district are controlled by minor folds, and it is these minor folds that constitute the subject of this paper.

North of the Rawlins uplift is the Sweetwater uplift, a major fold about one hundred miles long and forty miles wide that trends nearly due east. The Granite Mountains, which occupy the central part of this uplift, represent the higher peaks of the much dissected pre-Cambrian crystalline rock core, whose valleys and lower-lying parts are now filled and covered by nearly horizontal Tertiary sediments. These sediments form a nearly flat plain, above which the Granite Mountains rise like islands in a sea. On the south margin of the Sweetwater uplift, immediately adjacent to the Lost Soldier–Ferris district, are the Ferris and Seminoe mountains. The north side of the Ferris Mountains consists of pre-Cambrian crystalline rocks, adjacent to which, in a sharply upturned attitude, lie the Paleozoic and Mesozoic sediments that

[1] Max W. Ball, *op. cit.*, p. 51.



GEOLOGIC MAP OF THE RAWLINGS AND SWEETWATER UPLIFTS, WYOMING



EXPLANATION

Steele and Niobrara formations

Formations from base of Niobrara to base of Cambrian

Pre-Cambrian

Anticlinal folds with domes

Synclinal folds

"Map compiled from U.S. Geological Survey publications by C.J. Hares, E.E. Smith, and A.C. Veatch."

GEOLOGIC MAP OF THE RAWLINGS AND SWEETWATER UPLIFTS, WYOMING

form the south side of the mountains. In some places high on the flanks of the mountains the sedimentary beds are vertical or even slightly overturned.

To the southeast of the Ferris Mountains this sharp folding is replaced by faulting with thrust from the north, so that the crystalline rocks of the Seminoe Mountains now lie against the Cretaceous rocks of the Lost Soldier–Ferris district. The fault plane along which this overthrusting took place probably was almost vertical, and the horizontal displacement therefore slight, but even so the adjacent sedimentary beds of the Lost Soldier–Ferris district are somewhat overturned. It seems very probable that this overthrusting continues eastward as far as the Freezeout Hills. Westward from the Ferris Mountains the folding changes into faulting, but in this direction the amount of overthrusting is not so great as to the southeast.

The Sweetwater uplift, like the Rawlins uplift, is considered to have been developed mainly in pre-Wasatch time, but it differs from the Rawlins uplift in that the main deformation was followed by later movements of considerable magnitude. The importance and relations of these later movements are discussed below.

AGE OF THE FOLDS

The points to be brought out are two: (1) The folds of the Lost Soldier–Ferris district were not produced by the same forces that formed the Rawlins uplift, on which they were superimposed, but were produced by the forces that formed the Ferris and Seminoe mountains, to the north and northeast. (2) The Ferris and Seminoe mountains are considerably younger than the Sweetwater uplift, on whose south margin they rise, and probably represent a relatively late readjustment along this margin. If these points are established it follows that the folds of the Lost Soldier–Ferris district are younger than the Rawlins uplift and also younger than the main development of the Sweetwater uplift.

1. With the geographic setting of the Rawlins and Sweetwater uplifts in mind (Pl. III), attention should be directed to the alignment of the minor folds in the Lost Soldier–Ferris district. The downfold that structurally separates the Rawlins and Sweetwater

uplifts is the sharply flexed Camp Creek syncline, which lies only a few miles south of the Ferris and Seminoe mountains. It parallels the direction of the fault line along the southwest side of the Seminoe Mountains. North of this syncline there are no minor folds on the south slope of the Sweetwater uplift, but instead the abrupt upfold and thrust of the uplift itself, which is represented topographically by the Ferris and Seminoe mountains. South of the Camp Creek sycline the Rawlins uplift is represented by a long, comparatively gentle slope up to the granite axis of the upfold in the Rawlins Hills. This gentle north and northeast slope is interrupted by minor folds, including a long upfold that extends from the Wertz dome at the west and is accentuated in its eastward course by the Mahoney, Ferris, and G.P. domes. As the surface rocks are concealed by dune sand and alluvial wash the exact course of this upfold is not well known except at the high points mentioned. The axis of this upfold is parallel not to that of the Rawlins uplift but to that of the Camp Creek syncline, which in turn lies parallel to the Ferris-Seminoe line of deformation. From this close parallelism of structure it would appear that this minor upfold is the result either of the same forces that produced the Ferris and Seminoe mountains or of similarly directed forces. Certainly it could not have been the result of the forces that formed the Rawlins uplift. The north flanks of the Wertz and Mahoney domes and the northeast flanks of the Ferris and G.P. domes are steeper than the opposite flanks, a relation which also helps to indicate that the forces which formed them probably came from the north and northeast. To the north of the Wertz dome is the small Bunker Hill dome, which lies parallel to both the Wertz dome and the Camp Creek syncline. The course of the synclinal fold lying immediately south of the Wertz–Mahoney–Ferris–G.P. upfold is not clearly defined, although the syncline that separates the Mahoney dome from the Sherrard dome, and the Wertz dome from the Lost Soldier dome, is probably the westward extension of the Table Hills syncline. It was this downfold which divided the north end of the Rawlins uplift and formed the Lost Soldier dome as a distinct feature from the Wertz–Mahoney–Ferris–G.P. upfold, to the east. By considering the Table Hills syncline to have a westward extension, as above mentioned, its course also shows a

transverse direction to that of the Rawlins uplift and a parallelism to the Ferris-Seminoe line of deformation. The O'Brien Springs anticline, still farther south, shows a similar trend.

From the considerations above set forth it seems reasonable to suppose that the minor transverse folding in the Lost Soldier–Ferris district on the Rawlins uplift was produced by compressive forces that came from the direction of the Sweetwater uplift, to the north; and from the parallelism between these folds and the Ferris-Seminoe line of deformation, it seems reasonable to suppose further that these minor folds represent the more distant effects of the same forces that formed the Ferris and Seminoe mountains.

2. If the truth of the preceding arguments is conceded, there remains, to complete the purpose of this paper, proof that the minor folds of the Lost Soldier–Ferris district are decidedly younger than the major Rawlins uplift and the main development of the Sweetwater uplift. It has been shown that the axes of the minor folds are transverse to those of the Rawlins uplift, a relation which in itself implies, although it does not necessarily prove, that the minor folds are more recent than the uplift itself. The best proof, however, is to be found in showing that the Ferris and Seminoe mountains, which are of the same age as the minor folds of the Lost Soldier–Ferris district, are considerably younger than the main development of the Rawlins and Sweetwater uplifts.

The Ferris and Seminoe mountains may be spoken of as a marginal rim to the Sweetwater uplift. The central core of this uplift, now represented by deeply eroded granite, is a structurally much more highly elevated part of the uplift than the Ferris and Seminoe mountains at its margin. It is possible that at the time of the main deformation the central core of this major uplift was elevated to several times the height of the marginal rim; but the particular fact to be noted is that the Ferris and Seminoe mountains now attain a maximum altitude of 10,025 feet (as determined by triangulation and vertical angles), a considerably higher altitude than that of the peaks of the Granite Mountains, which now form the core of the uplift, and whose highest point, Hayden Peak, is reported by Hares[1] to have an altitude of only 8,040 feet. This

[1] C. J. Hares, "Anticlines in Central Wyoming," *U.S. Geol. Survey Bull. 641* (1916), p. 234.

difference of nearly 2,000 feet in altitude cannot be due to difference in erosion alone. Moreover, the Granite Mountains now show smooth surfaces, whereas the Ferris and Seminoe mountains are rough and rugged, a difference which indicates that the Ferris and Seminoe mountains are in a more youthful stage of erosion.

From these differences in altitude and in character of topography, therefore, it appears clear that the present Ferris and Seminoe mountains are younger than the Granite Mountains. This conclusion further indicates that the Ferris and Seminoe mountains are probably the result of a relatively late readjustment along the south margin of the Sweetwater uplift, and, from the nature of the structural features in this region, that this later deformation was a slight overthrust in which the Sweetwater area moved southward toward the Rawlins uplift.

How much later in geologic time than the main development of the Sweetwater and Rawlins uplifts this readjustment took place is not readily ascertainable. From unpublished field information pertaining to T. 28 N., Rs. 90 to 95 W., along the south edge of the Sweetwater uplift, gathered by Hares just beyond the south margin of the area covered in his report on "Anticlines in Central Wyoming,"[1] and by Smith along the north margin of the area covered in his report on "The Eastern Part of the Great Divide Coal Field, Wyoming,"[2] it is clear that there has been considerable readjustment in these townships since pre-Wasatch time, when the major upfolds were first developed. The significant evidence along this marginal zone is to be found in the nearly flat-lying Tertiary formations (Wasatch?) in the Green and Crooks mountains, at altitudes of 1,000 feet or more above the nearly flat-lying Tertiary beds (Wind River and White River formations) of the basin that now marks the Sweetwater uplift. It is also an interesting fact that the White River (Oligocene) formation of the Sweetwater basin—the "sea" in which the Granite Mountains stand out as "islands"—seems to be limited on the south by the fault zone that marks the boundary between the pre-Cambrian rocks of the Sweetwater uplift and the Paleozoic and Mesozoic formations in

[1] C. J. Hares, *op. cit.*, pp. 233–79.

[2] E. E. Smith, *U.S. Geol. Survey Bull. 341*, pp. 220–42.

T. 28 N., Rs. 89 to 95 W.[1] This greater altitude of the nearly flat-lying Tertiary beds south of the Sweetwater uplift and the possibility that the White River and Wind River formations lie only on the uplift itself are indicative of a readjustment movement here in post-Wasatch time and possibly as late as White River time. Ball[2] mentions the fact that the Hanna formation (Wasatch?) is vertical and overturned in the Freezeout Hills.

There has even been some post-Pleistocene movement in the region, for gravel-covered terraces in some places are reported to have slopes opposite to those of the present drainage.[3] These comparatively recent movements were probably of small magnitude and are cited principally to indicate that deformation did not necessarily cease here in the Tertiary period, but that warping has occurred in the Quaternary. It is possible that deformation has taken place even within recent times.

Inasmuch, therefore, as mountain-forming deformation has occurred here in post-Wasatch time and possibly as late as White River (Oligocene) time, or even later, it would seem that the Ferris and Seminoe mountains should be regarded as the local results of this late movement of readjustment along the south margin of the Sweetwater uplift. Although the exact time when these mountains were formed has not been ascertained, it seems nevertheless that they must be considerably younger than the main deformative movements which produced the Sweetwater and Rawlins uplifts. If it is regarded as established that the Ferris and Seminoe mountains are due to a late and possibly final spasm of mountain-forming movements in this general region, it should probably be conceded that the minor domes and anticlines of the Lost Soldier–Ferris district are also due to the same movements. Credit must be given to Ball[4] for his recognition of a marked difference between the deformation features of the Ferris and Seminoe mountains and those of the Wyoming mountains of the

[1] No positive statement to this effect can be made, for the relation was noted over only a small area by the writer, and the evidence gleaned from the unpublished work of Hares and Smith above cited, though apparently supporting the inference, does not fully confirm it.

[2] *Op. cit.*, p. 55.

[3] K. C. Heald, personal communication.

[4] *Op. cit.*, p. 59.

usual type, but although he realized that this difference existed, he did not consider its significance in relation to the age of minor folds of the Lost Soldier–Ferris district.

ECONOMIC CONSIDERATION

The minor folds of the Lost Soldier–Ferris district are shown above to be distinctly younger than the Rawlins uplift, on which they are superimposed, and the question arises as to the relation of this difference in age to the accumulation of the oil and gas in the Lost Soldier, Wertz, Mahoney, Ferris, and G.P. fields. As the Rawlins uplift was in existence in pre-Wasatch time, it is obvious that any oil and gas that prior to the minor folding of the Lost Soldier–Ferris district had been formed or had migrated a short distance above the margin of the uplift, where the catchment areas of the present fields are situated, must surely have been lost through the eroded edges of the formations on the top of this major uplift. The oil and gas of the present fields and of possible unproved pools in this region must have been formed largely by the dynamo-chemical action of the later deformational forces that caused the minor flexing. Some oil and gas of earlier distillation may have been already present within the catchment areas of the existing fields, but this oil and gas must have been only a fraction of that which was formed within the area embraced by the Rawlins uplift. The oil and gas now available in this district for the use of man must represent, therefore, merely a remnant of the total quantity derived from the mother-material which the rocks of this region originally contained.